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***NOAA PROTOCOLS FOR FISHERIES ACOUSTICS SURVEYS
AND RELATED SAMPLING***

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NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling

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Introduction

In response to Vice Admiral Lautenbacher's September 16, 2002 memo that mandated a review of current protocols and a publication of new protocols, NOAA Fisheries began a discussion on developing national and regional protocols for acoustic-based surveys. The objective of the protocols is to "ensure that all aspects of preparation for [trawl] surveys and [trawl] survey procedures are consistent and in keeping with the highest quality standards to provide for survey data accuracy and consistency from one survey to the next". For these protocols, "trawl" is replaced with "fisheries acoustics". Members from the Alaska Fisheries Science Center (AFSC), Northeast Fisheries Science Center (NEFSC), Northwest Fisheries Science Center (NWFSC), and Southwest Fisheries Science Center (SWFSC) participated in a workshop during April 23-24, 2003 to develop a protocol framework that would be consistent among all centers, encompass acoustical aspects of conducting fisheries independent acoustical surveys, and include survey methods as related to acoustical surveys.

The overall goal of fisheries acoustical surveys is to provide age-dependent, fishery independent estimates of species-specific biomass and abundance. These protocols are designed to provide guidelines for collecting, processing, and analyzing acoustical and related biological and physical oceanographic data. These protocols are to be used for existing fisheries acoustics surveys, and to provide guidance for designing new surveys. These protocols are limited to mobile surveys using downward looking transducers of one or more frequencies. In addition, protocols for collecting and processing other data (*e.g.*, biological and physical data) are provided only to the extent that these data are incorporated in acoustical surveys. This document is based on current practices and state-of-the-art knowledge and equipment. Additional protocols will be developed when other types of instrumentation or other types of surveys become routine, and when scientific and technological advancements necessitate modification of these protocols. Efforts have been made to develop a format that will allow efficient additions or modifications of current protocols via quantitative consideration of associated measurement errors.

Acoustic-based biomass and abundance estimates are used in assessments as relative indices or absolute numbers. These protocols are also designed to provide guidelines for supplying assessment scientists with objective information and knowledge of the levels of uncertainty associated with the acoustical estimates.

This document is arranged as follows. Center-specific background is given to provide information on each Center's personnel and general support. A short review of acoustical methods relative to performing surveys is provided. This review sets the foundation for the protocol framework. Lastly, the methods for collecting, processing, and analyzing acoustical and related biological data are given. Center and/or regional protocols are detailed in each region's protocol document.

Center Background

AFSC

AFSC – The Alaska Fisheries Science Center (AFSC) conducts acoustic-trawl surveys in the Bering Sea and Gulf of Alaska. The target species is walleye pollock (*Theragra chalcogramma*). Surveys are conducted aboard the NOAA Ship Miller Freeman and, beginning in 2005, the NOAA Ship Oscar Dyson. Field seasons include approximately six weeks in the winter and three months in the summer. Abundance-at-age estimates from these surveys, along with bottom trawl survey data and fishery catch data, are used to model population size, and, in turn, to establish quotas for the commercial fishing industry under the auspices of the North Pacific Fishery Management Council. The acoustics group within the Midwater Assessment and Conservation Engineering (MACE) Program is comprised of eleven fisheries biologists and three information technology specialists. All employees are full-time and base-funded.

NEFSC

The Northeast Fisheries Science Center (NEFSC) fisheries acoustics group currently has two FTE's affiliated with the Survey Branch and one FTE affiliated with the Population Dynamics Branch. Two FTE's are base funded and the other FTE is funded on a congressional budget "line-item". The NEFSC fisheries acoustics group focuses on estimating Atlantic herring (*Clupea harengus*) spawning stock biomass with an annual six-week survey conducted in the fall.

NWFSC

Scientists from the Northwest Fisheries Science Center (NWFSC) and Canada Department of Fisheries and Oceans (DFO) conduct periodic joint acoustic surveys of Pacific hake, *Merluccius productus*, along the west coasts of both countries. The surveys are a key data source for the joint Canada/US Pacific stock assessments and act as the foundation for advice on harvest levels. Integrated acoustic and trawl surveys, used to assess the distribution, abundance and biology of Pacific hake, have been historically conducted triennially by Alaska Fisheries Science Center (AFSC) since 1977 and annually along the Canadian west coast since 1990 by Pacific Biological Station (PBS) scientists. The triennial surveys in 1995, 1998, and 2001 were carried out jointly by AFSC and DFO. Following 2001, the responsibility of the US portion of the survey was transferred to Fishery Resource Analysis and Monitoring (FRAM) Division scientists at NWFSC. A joint survey was conducted by FRAM and PBS scientists in 2003, marking not only the change in the US participants but also a change to a newly-adopted biennial survey regimen. The FRAM Division acoustics group currently is composed of five full-time, base funded fisheries biologists.

SWFSC

The Southwest Fisheries Science Center (SWFSC) conducts quantitative acoustical surveys for Antarctic krill in support of the U.S. Antarctic Marine Living Resources Program (AMLR) and the fisheries management efforts of the Antarctic Treaty's Commission for the Conservation of Marine Living Resources (CCAMLR). These

acoustical surveys are supported by two FTE's in the SWFSC's Antarctic Ecosystems Research Division (AERD) and one FTE in the SWFSC's Advanced Survey Technologies Program (AST). The AERD and AST each employ contractors to assist with the associated surveys, data processing, and technology development. AERD's FTEs and one-quarter of ASTs FTE are funded on a congressional budget "line-item" – AMLR. Three-quarters of the AST FTE are base funded.

Acoustical Background

Acoustical technologies are effective and efficient methods for sampling fish and zooplankton in the water column. Fisheries acoustics methods are analogous to remote sensing techniques and advantageous to other sampling methods as nearly the entire water column can be sampled quickly (sound travels approximately 1500 m s^{-1} in water), areal coverage is continuous, data resolution is on the order of tenths of meters vertically and meters horizontally, and data can be post-processed in a variety of ways. Limitations of acoustical technologies include: near-boundary areas (near surface and seabed) are not well sampled, species identification is difficult, and obtaining biological information (e.g., age, maturity, diet) is very difficult. Optimally, fisheries acoustic surveys integrate acoustical technologies with other sampling methods such as net catch and temperature-salinity data to estimate population abundance.

Underwater acoustical systems used in fisheries consist of an echo sounder that produces a transmit voltage, processes returned signals, and transmits data to computers, and a transducer that converts the transmit voltage to a pressure wave (a "ping") and then converts echoes from targets in the water column back to a voltage. The downward-looking transducer is mounted on the hull or drop keel or in a towbody to sample the water column directly beneath the ship while the ship steams along transects. The SONAR equation defines the sound propagation and interaction with targets in the water column.

SONAR Equation

The RADAR equivalent of the SONAR equation is accurate, easily understood, and therefore useful. The equation detailing volume scattering (S_v [dB]) is:

$$S_v = \frac{P_R 32\pi^2}{P_T G_0^2 r_0^2 \lambda^2 c \tau \psi} r^2 10^{2\alpha r} \quad (1)$$

where P_R is the received power [Watts], P_T is the transmitted power [Watts], G_0 is the system gain, r_0 is the reference range ($r_0=1 \text{ m}$) [no units], c is the speed of sound in water [m s^{-1}], λ is the acoustic wavelength [m] ($\lambda = c/f$, where f is the acoustic frequency [Hz]), τ is the transmit pulse duration [sec], ψ is the two-way integrated beam pattern, r is the range [m] from the transducer, and α is the acoustic attenuation [dB m^{-1}]. Speed of sound is dependent on temperature, salinity, and pressure (depth).

It is important to note that parameters in equation 1 (τ , ψ , λ , α , and G_0) are sound speed, frequency, and system (echo sounder and transducer) dependent, and interactions

among these parameters affect measurements of Sv in linear and non-linear ways. Analyses of uncertainty associated with these parameters must incorporate these interactions.

The SONAR equation defines the interaction of the pressure wave with the environment, targets, and the echo sounder. The next step is to convert the acoustical measures (Sv) to a population estimate. We define a general equation of this conversion that will provide a framework for the protocols.

Generalized Equation

The general equation used to convert volume backscattering measurements to population biomass estimates is:

$$B_i = \frac{CE_i}{\sigma_i} D_i A_i \quad (2)$$

where C is the calibration parameters/coefficients, E_i is the measured acoustical energy, σ is the estimated backscattering cross-sectional area, D is the numerical density to biomass density conversion, and A is the survey area. Subscript “i” denotes the target classification level (*i.e.*, species, age- or length-class, or target type).

Equation 2 provides a framework for this protocol. Based on this equation, five general categories are defined: system calibration and performance (C), volume backscattering measurements (E), target strength (σ), acoustical-biological conversions (D), and survey design (A). The Methods section details specific methods for each of these categories. Topics under each category are detailed with a consistent structure:

Definition & Importance: Description of the topic and why it is important to the acoustical survey process.

Techniques: Details on the procedures and methods (how, when, where, and documentation).

Error: Discussion of the random and systematic errors, and accuracy and precision of the measurements.

Considerations: Description of remediation procedures and improvements in techniques or measurements.

Methods

Calibration and System Performance

Calibration

Definition & Importance

Calibrations characterize system parameters relative to expected standard values.

System parameters specific to scientific echo sounders are: gain constants (G_0), pulse duration (τ), two-way integrated beam pattern (ψ), time-varied gain (TVG), the speed of sound in the water (c), sound attenuation (α), and the transmit power. Calibrations are conducted to ensure that the echo sounder and transducer are operating properly, to

ensure system stability over time (i.e., among survey periods), and to allow inter-echo sounder comparisons.

Echo sounder calibrations conducted on board NOAA fisheries research vessels use the standard-target method (Foote *et al.*, 1987), which relates acoustical energy to an absolute standard. The standard-target method calibrates the overall acoustical system, which consists of the echo sounder, transducer, and cable. The calibrations consist of two parts: on-axis sensitivity and beam pattern measurements. On-axis target strength and S_A measurements calibrate gain parameters and beam pattern measurements supply beamwidth and angle offset values.

Techniques

Before conducting a calibration important issues to consider are:

- 1) The calibration should be conducted in the same environmental conditions (water temperature and salinity) as are experienced during the survey.
- 2) Water depths must be sufficient to exceed near-field limitations and/or system limitations for the echo sounder frequencies to be calibrated (Table 1).
- 3) Calibrations must be conducted before the survey begins to establish proper echo sounder operation, and after or near the end of the survey to ensure no significant changes have occurred. Additional calibrations during the survey are valuable for maintaining system performance and ensuring high-quality data.
- 4) Calibrations must be conducted with the same pulse durations, transmit powers, and bandwidths used during the survey.

Software

Echo sounder manufacturers provide detailed instructions and software programs for calibrating their systems. These instructions must be followed to ensure proper calibration and system stability. Because software upgrades occur, software version identification (both calibration software and echo sounder software) should be documented.

Regional Protocols

Standard values

Table 1 provides a list of common standard values for calibration. The calibration sphere target strength is dependent on the water temperature and salinity (*i.e.*, sound speed dependent). The copper spheres specified for each frequency have been shown to be “optimal” in that the target strengths of the specified spheres vary minimally for a normal range of temperatures and salinities (Foote, 1982; 1983a). However, one should confirm that the theoretical TS is valid for the measured environmental conditions.

Table 1. Calibration standard values. Calibration sphere measurements are the sphere diameter. ‘Cu’ denotes a copper calibration sphere, and ‘WC’ denotes a tungsten carbide with 6% cobalt binder calibration sphere. The ‘EK500 Minimum Target Range’ applies to the Simrad EK500 and was derived as a combination of the far field of the transducer and electronic limitations of the echo sounder.

Frequency [kHz]	Calibration Sphere	EK500 Minimum Target Range [m]	Nominal TS [dB]*
12	45 mm Cu	35	-40.4
18	64 mm Cu	22	-34.4
38	60 mm Cu	10	-33.6
38	38.1 mm WC	10	-42.2
120	23 mm Cu	10	-40.4
120	38.1 mm WC	10	-39.6
200	13.7 mm Cu	10	-45.0
200	38.1 mm WC	10	-39.5

Regional Protocols

On-axis sensitivity

On-axis sensitivity is measured by positioning the calibration sphere on the acoustic axis of the transducer. The target strength gain is derived from the measured on-axis target strengths relative to the target strength of the calibration sphere.

Regional Protocols

Beam pattern measurements

Beam pattern measurements are acquired by positioning the calibration sphere at many different angular locations within the acoustic beam. For split-beam transducers, echo strength is compensated by the angular location of the target in the acoustic beam. A target’s location is derived from electrical phase differences among the quadrants. Transducer parameters such as the beamwidth, transmit-receive directivity response, and two-way integrated beam pattern, are supplied by the transducer manufacturer. Calibration software packages may provide beam width and angle offset parameter estimates based on the beam pattern measurements. Use of these parameters is based on the individual center’s protocols.

Regional Protocols

S_v Calibrations

Echo sounder calibrations for S_v measurements involve positioning the calibration sphere on the transducer axis and measuring S_v relative to the theoretical value. The theoretical S_v is based on the target strength and range to the calibration sphere. The primary result of the S_v calibration is the S_v gain.

Regional Protocols

Oceanographic Data

A vertical temperature and salinity profile should be obtained to calculate sound speed prior to every calibration. The profile must encompass the calibration depths. This profile should be compared to temperature and salinity profiles obtained during the survey to ensure similar physical environmental conditions between the calibration exercise and the survey.

Regional Protocols

Error

The standard target method for calibrating echo sounders is used to calibrate the overall acoustical system (combined transmit and receive echo sounder components, transducer, transducer cable, and the electrical supply) to an absolute standard. Thus the calibrations reflect an integration of the echo sounder, transducer, and shipboard electrical system. If any component of this system changes (e.g., the shipboard electrical system, transducer cable length) during the survey, the echo sounder must be recalibrated.

Errors and tolerances associated with calibrations are relative to the system precision. Angular target locations derived from split-beam systems are dependent on the A/D sampling rate and the ability to measure electrical phase differences among the quadrants. Target strength measurements are dependent on the dynamic range and the A/D sampling rate. Thus tolerances for calibration results are relative to the system precision. For example, Foote (1983a) and MacLennan and Simmonds (1992) suggest a tolerance in on-axis target strength measurements of ± 0.2 dB (TS $G_0 \pm 0.1$ dB) for the Simrad EK500.

Variability in system parameters due to environmental conditions, primarily temperature, has been observed in the EK500. The temperature effect appears to influence the 120- and 200-kHz transducers more than other frequencies, and is observed even when attenuation and sound speed are properly established. This effect is believed to be a transducer design issue.

Considerations

Remediation

Echo sounder manufacturers should provide detailed diagnostic and evaluation routines. General diagnoses for the EK500 are:

The 'test' values for the EK500 are a measure of the transducer performance and are acquired for each transducer. A 'test' value not within the specified tolerance (refer to the Simrad EK500 manual for values and tolerances) is an indication of a broken connection in one or more of the wires to the transducer. Impedance and continuity tests should be performed to determine which wires are severed, and the connections must be repaired. The cause of the broken connection should be determined and rectified.

If the TS and/or Sv gains (G_0) are not within tolerance, ‘test’ values (for the EK500) may indicate a problem with the transducer or transducer cable. If this is not the problem, then a full set of diagnostics must be completed on the echo sounder to determine the cause of the problem. The survey should not continue until the problem is rectified.

Improvements

Improvements in calibrations include the ability to measure the angular location of the target independent of the echo sounder.

System Performance

Definition & Importance

System performance is the evaluation of echo sounder and transducer performance during a survey.

Periodic monitoring and evaluating of system performance is necessary for ensuring high-quality acoustical data during surveys. System performance deals with the internal electronics and processors and transducer and cable, not with interference introduced from external sources (System Degradation section).

Techniques

Regional Protocols

Error

Reduced or variable system performance will affect target strength and volume scattering measurements, and ultimately population estimates. Systematic errors in system performance include a change in transducer sensitivity over time or with other shipboard operations. Random errors can be very difficult to diagnose, but every effort should be made to diagnose the problems. If systematic and/or random errors are found, evaluation of the effects of these errors should be done during or after the survey.

Considerations

Remediation

Echo sounder manufacturers should provide detailed diagnostic and evaluation routines. These routines should be used to identify and evaluate the problem.

For the EK500, survey operations should be suspended if the ‘Test’ values are out of tolerance (refer to the Remediation section under Calibrations). After the problem is resolved, the survey can continue.

If individual targets do not appear in all quadrants, survey operations should be suspended and the problem diagnosed.

Improvements

Improvements in monitoring system performance include continuous monitoring of the output echo sounder power or voltage to the transducer. The ability to monitor

voltage to the transducer would provide real-time evaluation of the echo sounder performance.

Data Management

Documenting and archiving calibration data and supporting information is critical. In addition to data and derived values acquired from the calibration software, data should be collected directly from the echo sounder. Echo sounder data include high-resolution sample, individual target strength, and volume scattering data. These data should be archived immediately after conclusion of the calibration. Supporting information should be documented and archived with the calibration data.

Calibration data, such as the data collected by the calibration software and the echo sounder, and associated meta-data should be archived on-board upon completion of each calibration exercise. These data are downloaded to shore-based computers and permanently archived for each calibration.

Regional Protocols

Volume Backscattering Measurements (E_v)

Data Collection

Definition & Importance

Volume backscattering (S_v , m^2/m^3) is the summation of echo energy (E_i) within a sampling volume.

S_v is a measure of the relative density of organisms and the primary measurement for acoustically estimating fish densities and abundance. Equation 1 (Acoustical Background section) details the dependency of S_v on sound speed (c), acoustical frequency (f) and wavelength (λ), pulse duration (τ), two-way integrated beam pattern (ψ), S_v gain (G_0), and attenuation (α).

Techniques

Echo Sounder Parameters

Scientific echo sounders allow the user to input the parameters: G_0 , c , τ , ψ , and α and to choose the ping interval. The acoustic frequency (f) is defined by the echo sounder. Choosing echo sounder settings should be done with the understanding of the interdependency of these parameters and how they affect S_v measurements (Furusawa, 1991).

The S_v gain (G_0) is obtained from the echo sounder calibration (Calibration section). Choice of the pulse duration (τ) is dependent on the objectives and conditions of the survey. For higher resolution of individual targets, a shorter pulse duration is desirable, whereas a longer pulse duration is desirable for greater ranges because of a higher signal-to-noise (SNR) ratio. The echo sounder must be calibrated at the pulse duration used during a survey. Sound speed (c) is dependent on water temperature and salinity, so setting the sound speed requires *a priori* knowledge of the environmental conditions expected during the survey. The two-way integrated beam pattern (ψ) or beam width is defined by the transducer specifications supplied by the manufacturer. Sound attenuation (α) and acoustic spreading combine for the total acoustical transmission loss. To correct

for spreading and attenuation losses, a $20\log_{10}(R)$ time-varied gain, where R is range, is applied to the S_v data. Sound attenuation is dependent on the acoustic frequency and water temperature and salinity. Similar to the sound speed, setting α requires *a priori* knowledge of the environmental conditions. If significant environmental changes occur, the attenuation parameter and sound speed should be recalculated and set for those conditions. It is essential to document all initial echo sounder parameter settings and any changes made to them, either during data collection or during post-processing.

Regional Protocols

Software

Upgrades to echo sounder firmware versions and post-processing software versions are developed by manufacturers to correct software errors and to improve performance. When software is changed significantly, output for the two versions should be compared to ensure that the results are as expected. If not, analysis is needed to determine the source of the unexpected difference. Documenting firmware and software versions aids in interpreting any observed differences in results between old and new versions, and in making corrections, if necessary.

Regional Protocols

GPS

Integrating Global Positioning System (GPS) data with S_v measurements is critical for population estimates. GPS data are required for scaling S_v measurements to the survey area (Sampling section). Choices of positioning instrumentation and data are dependent on the availability of the on-board GPS systems, performance of the GPS over the survey area, compatibility of the GPS system with the echo sounder, and the desired accuracy and precision of the GPS data. Proper practice requires monitoring GPS output during data collection, documenting the type of GPS data used, and documenting data storage and retrieval procedures.

Regional Protocols

Oceanographic Data

Sea-surface profiles of temperature and salinity may be collected continuously during a survey. Vertical profiles may be collected routinely and at regular intervals during the survey and in close temporal and spatial proximity to trawl sets. Temperature and salinity data can also be useful for measuring the physical environment for ecological studies.

Oceanographic sensor manufacturers provide calibration, operational, and diagnostic instructions. These instructions should be followed.

Regional Protocols

Error

Because S_v data are the primary measurements used for acoustical estimates of species density and abundance, an understanding of the uncertainty associated with S_v measurements is invaluable. Linear and non-linear relationships among the parameters and environmental conditions can make understanding and quantifying uncertainty in S_v measurements difficult. Additionally, random and systematic errors in parameter settings relative to true values increase the uncertainty in density and abundance estimates.

Considerations

Remediation

If a parameter is incorrectly set during the survey, correct the parameter value, and document the change. Record the old and new values, date and time of modification, and other data indices so that the data collected prior to the modification can be reprocessed using a software package such as Echoview (SonarData, Tasmania, Australia).

Improvements

A single sound speed is currently used to describe the vertical sound speed profile, which is appropriate when the water column is mixed from surface to bottom. However, thermoclines (temperature gradients) and haloclines (salinity gradients) often exist, potentially with 10° or more temperature and 1-3‰ salinity changes. Simulations should be conducted to determine the effect of using a single sound speed value in the presence of pycnoclines or over large geographical areas. An error analysis should be completed to assess the effects of variable environmental conditions (expected and observed) on S_v measurements.

Detection Probability

Definition & Importance

Detection probability refers to the likelihood of detecting the target organism.

Fisheries acoustics surveys are conducted to estimate species-specific density and abundance. Density and abundance estimates can be further categorized into age or length classes. Anatomical characteristics (e.g., the presence or absence of a gas-bearing structure), behavior (diel vertical migration, affinity for the seabed, active swimming), spatial and temporal distribution, ontogenetic changes, and frequency dependent backscattering affect S_v measurements and the interpretation of S_v to estimates of fish numbers or biomass.

Data collection parameters are set to acquire data that can be used for a variety of purposes, whereas post-processing parameters and techniques are optimized for single species. In other words, data collection attempts to maximize the detection probability for a wide variety of organisms, while post-processing attempts to maximize the detection probability for the species of interest while minimizing the detection probability for all other organisms. Techniques for enhancing target species detection probability and reducing non-target species S_v include applying a threshold, selecting optimal survey

sites and times (Survey Design section) and employing multiple acoustic frequencies (Classification sub-section).

The underwater, radiated vessel noise can potentially cause behavioral changes in organisms. Behavioral changes include a change in the spatial orientation of the organism, changes in activity such as swimming, changes in the vertical distribution, and/or avoidance of the vessel (horizontal distribution). Modification of orientation and activity affect the backscattering strength of the individual organisms. Changes in vertical distribution can affect the backscattering strength of individuals and whether the organism is located in the acoustic beam. Changes in horizontal distribution, such as vessel avoidance, influence whether the organism is located in the acoustic beam (i.e., whether the organism is sampled or not).

Techniques

Thresholding

Acoustical backscatter by organisms with a gas-bearing structure such as a swimbladder is significantly greater than for organisms without a gas-bearing structure. This attribute can be used to reduce or eliminate the S_v from non-gas-bearing organisms by setting a volume backscattering threshold greater than the detection probability for these organisms while retaining S_v for the gas-bearing organisms. No setting can discriminate between fish and plankton or other non-target species with 100% accuracy. Some small fish targets are unavoidably discarded, just as some small amount of acoustic return from unwanted sources is included. The goal in choosing an S_v threshold setting is to find an optimal balance between eliminating non-target species S_v and preserving the target species S_v . Because some error is involved in applying a threshold, it is important to maintain consistency between surveys, i.e. the data collection threshold choices should be the same for all surveys in a time series.

It is important to distinguish between S_v threshold and TS threshold. The target strength threshold applies to backscattering by individuals. S_v threshold applies to the accumulation of backscattering by multiple individuals.

Regional Protocols

Range

The detection probability is a function of range: targets farther from the transducer have a lower probability of detection. The decrease with range is related to the dynamic range of the echo sounder, the noise level of the signal, and transmission loss of the acoustical signal. As range increases, the signal to noise ratio (SNR) decreases (signal decreases and noise increases) and echo amplitudes from targets in the water column drop below the noise level or S_v threshold. This effect is a particular concern when surveying deep water species or species without a gas-bearing structure. It is also necessary to take into account the SNR for the target species as a function of depth in order to plan a survey or to interpret the results.

Regional Protocols

Acoustic Dead Zones: Near surface and near bottom

Although acoustical methods are efficient for water column measurements, they are less effective at measuring backscattering by organisms near boundaries such as the sea surface or sea floor. Vessel-mounted or surface towed downward-looking transducers do not sample the water column above the depth of the transducer. Additionally, data within the transducer near field are not valid for survey estimates. For post-processing, a surface exclusion zone is selected, accounting for both transducer depth and the near field.

Echoes from fish close to the bottom may merge with the much stronger echoes from the bottom itself. Because the bottom echo is so much larger than that from fish, quantitative survey estimates of fish abundance depend strongly on properly distinguishing between the bottom and fish targets (MacLennan and Simmonds 1998). The problem of discriminating between fish and the bottom is further complicated because for each sound pulse transmitted by the echo sounder, there exists a zone near the seabed that is not sampled, the acoustic 'deadzone' (Ona and Mitson 1996). In addition, the bottom-tracking algorithm in use on modern echo sounders (e.g. Simrad) includes a 'backstep', a user-selected distance from the echo sounder bottom-detected depth, where the energy contribution of the bottom echo is considered negligible. In rough topography or rough seas, the bottom detection algorithm fails more frequently, resulting in the intrusion of bottom echoes into the water column, even with an increase in the backstep value. These bottom-tracking failures must be corrected manually during post-processing. Corrections for unsampled fish in the dead zone and in the zone above the bottom within the backstep interval must also be made in post-processing, to generate a more representative abundance estimate for fish in the water column.

Regional Protocols

Animal Behavior

For acoustical measurements, organism behavior is a combination of activity and spatial orientation of the organism. For targets that are non-spherical in shape, acoustic backscattering strength in the geometric scattering region is strongly dependent on the angle of the organism relative to the transducer. In general, backscatter in the geometric scattering region is strongest when the major axis of the organism is perpendicular to the transducer's acoustic axis and weakest when the organism's major axis is parallel to the acoustic axis. Activities such as swimming, feeding, or vertical migrations potentially affect S_v measurements by increasing or decreasing detection probabilities. Variability in backscattering strength as a function of organism orientation and behavior combined with S_v thresholding may affect the detection probability. For example, when the distribution of organism orientations is centered near perpendicular to the transducer, the detection probability may be high. When these organisms orient at angles near parallel to the acoustic axis, the S_v decreases and potentially below the S_v threshold.

Vertical and horizontal migrations can affect detection probabilities. Migration into or out of the near-surface or bottom zones during the survey will nearly eliminate the detection probability for these organisms. Horizontal migrations may take the organisms out of the survey area or outside of the acoustic beam.

Regional Protocols

Vessel Noise and Avoidance

All vessels radiate underwater noise (Urlick 1983). Fish species are able to detect this vessel noise over a range of frequencies from tens to at least several hundred Hz (Mitson 1995). Whether the fish react to the vessel noise, thereby altering their behavior and detection probability has been the subject of much research (Ona and Godo 1990, Mitson 1995, Handegard et al. 2003). Vessel avoidance is defined as a zero detection probability resulting from a change in behavior due to the vessel noise, but even less severe changes in behavior may affect S_v measurements and the detection probability. The ICES Cooperative Research Report No. 209 (Mitson 1995) provides guidelines for making noise range measurements and gives recommendations for dealing with vessel noise and avoidance, including, in particular, proposed standards for underwater radiated noise levels in the design of new vessels. Underwater noise levels should be determined for vessels to be used in fishery research that do not conform to the ICES standard. Mitson (1995) recommends that ‘observations should be carried out whenever possible to relate the known (measured) characteristics of a vessel to any observed avoidance behaviour of fish, or to noise affecting acoustic survey equipment.’

Regional Protocols

Multiple scattering and shadowing

The theory of the linear summation of individual echo strengths within a sampling volume is valid for a wide range of organism densities (Foote, 1983b). However, when organism densities are high, multiple scattering (echoes have scattered off multiple individuals before returning to the transducer) and shadowing (similar to bubble attenuation, the pressure wave amplitude decreases at a greater rate than explained by transmission loss) have non-linear effects on the summation of echoes within a sampling volume (MacLennan 1990, Toresen 1991).

Regional Protocols

Error

Uncertainty in detection probabilities of target and non-target species affects interpretation of S_v measurements and the efficacy of post-processing techniques. Systematic and random changes in detection probabilities during the survey will have linear and non-linear effects on S_v measurements. A systematic change in fish orientation, for example, from a horizontal to a more vertical position during vertical migration, will cause a decrease in the volume backscattering. If factors such as orientation are not taken into account, it might appear that there are fewer or smaller fish. Thresholding the S_v data could compound the error in abundance estimates.

Considerations

Remediation

The survey design (timing and location) should consider potential systematic changes in detection probability. If systematic changes in detection probability are discovered, either a change in the survey design is required or analyses should be conducted to determine a correction factor. If significant changes are made to the survey vessel that are expected to affect vessel-generated noise (e.g. major modifications to propeller, generators, or main engine), noise-range measurements should be conducted.

Improvements

The first of four low-noise NOAA survey vessels is currently under construction and will begin survey work for the AFSC in 2005. The NEFSC, NWFSC, and SWFSC will each receive one of the other vessels. All four vessels will meet ICES noise standards, which will greatly reduce the potential for vessel noise affecting fish behavior.

Classification

Definition & Importance

Classification is the discrimination and identification of organism type or species during an acoustic survey. Discrimination refers to the process of separating targets of interest from other targets and noise.

Fisheries acoustics surveys are designed to provide density and abundance estimates, usually age or length-based, for one or more target species. A critical requirement, therefore, is to separate backscatter of the target species from all other backscatter. This is done in two steps. First, noise from unwanted sources such as plankton (if not the object of the survey), air bubbles, bottom echoes, and electrical interference is removed. Then, the remaining targets are apportioned between species or groups of species of fish or plankton. The main technique used for this purpose is inspection of echograms. Partitioning of echo integration data is aided by application of an appropriate S_v threshold (S_v Detection Probability section) and a survey design chosen so that the target species is favorably distributed away from boundaries and in schools or layers that are mono-specific and easily identified. The main source of information used to validate interpretation of echograms is net catches. Other potential sources of validation data are underwater video and use of multiple frequency acoustic data.

Techniques

Single Frequency

The standard frequency for estimating density and abundance of marine fish species is 38 kHz; and for krill, 120 kHz. Echo sounders operating at 38 kHz are able to detect fish with swimbladders, and aggregations of macrozooplankton such as krill. Fish without swim bladders are more difficult to detect with either of these two frequencies. However, the ability to measure backscatter from a diversity of species at reasonable ranges make both of these frequencies useful. A disadvantage is that separating backscatter from target species can be difficult. Thus, multiple frequency data are often utilized in conjunction with biological sampling as an aid in classification of the acoustic returns (Reid 2000).

Regional Protocols

Multiple Frequency

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. The efficacy of multiple narrow-band frequencies in classification of acoustical backscatter is based on the frequency-dependent scattering by different types of organisms. In the simplest application, echograms from several frequencies are visually compared, and qualitative differences are noted and used to help classify targets or layers. Multi-frequency algorithms have been developed for some applications to make quantitative comparisons, but they are not in use at NOAA in routine surveys of fish.

Regional Protocols

Biological Sampling

Trawls

Pelagic trawls are the primary tools for validating the species composition of acoustic backscatter and for obtaining length frequency distribution, age, and other biological information. Trawls provide the best available method of obtaining relatively unbiased estimates of species and size composition (Simmonds *et al.* 1992). Appropriate trawl gear should be chosen with full consideration of its size in relation to the towing power of the vessel. The number, locations, and timing of trawl sets are dependent on the objectives of the survey, but the main idea is to obtain catches that are representative of the species composition and the length-frequency distribution of organisms detected acoustically. This is a difficult to accomplish because nearly all biological sampling methods are species and size selective.

Different parts of a school or layer may have different length-frequency distributions or even different species compositions, and a single school may not be representative of the cluster of schools in an area. For this reason, hauls should include more than one small school and more than one part of a large school or layer if this can be done without taking a sample that cannot be handled by the vessel.

Trawls in acoustical surveys are targeted on schools or layers detected by the echo sounder. Such aimed trawling requires effective net mensuration instrumentation. Net mensuration instrumentation choices include door and wing sensors, third-wire sensors, depth sensors, and head- and footrope sensors. Although net catches for hauls made during acoustical surveys are not used for estimating fish biomass, it is still important that trawl procedures are consistent between and within surveys. Net mensuration information is essential for maintaining consistency and evaluating performance in trawl procedures.

In many cases trawl catches are too large to sample in their entirety, and must be sub-sampled. Even when an entire trawl catch is processed for species composition by weight and number, additional information such as age, fish length and sex cannot, in most cases, be taken from all captured specimens. Thus, random sub-samples of the

catch should be taken to obtain the biological information. Determination of the sub-sample size should be guided by statistical principles.

Protocols for setting and retrieving the net should be based on the type of net and vessel. Vessel personnel play a key role in maintaining repeatability in net deployment, and should be briefed on the importance of adhering to protocols. They should have a copy of the protocols and should be consulted in the development of the trawl field manual. Routine inspections of the gear should be made to confirm that it conforms to design specifications. This is especially important after nets have been damaged and repaired in the field.

A schedule for calibration and maintenance of net mensuration equipment should follow the manufacturer's recommendations. If possible, spare parts or complete backup systems should be available for all critical net mensuration instruments.

Regional Protocols

Underwater video.

Underwater video and still-camera systems provide visual identification of species and has the potential to document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towbody orientation sensors (tilt, roll, and pitch) are also required to quantify the data for behavioral measurements.

Regional Protocols

Bottom Tracking

Echo sounders and post-processing software use algorithms to detect the seabed. Performance of these algorithms depends on bottom type and topography. On hard, flat substrate, the algorithms perform well. On soft substrate, or rugged topography, the ability to accurately detect the water-seabed interface is reduced. The echo return from the seabed is typically orders of magnitude greater than that from organisms, so it is critical to eliminate seabed echoes from the water column data. Improper bottom detections are found and corrected manually through inspection of the echograms. Bottom detection parameters used during data collection and in post-processing should be documented.

Regional Protocols

Error

Uncertainty in classifying and separating acoustic backscatter by target species from non-target species is a potential source of error in acoustic estimates of density and abundance. Possible errors include misclassification (either incorporating volume backscatter by non-target species or eliminating volume backscatter by target species), scaling acoustic data with trawl catch data that are not representative of species composition or length- and age-frequency distributions, incorporating seabed echoes in water column data, use of an inappropriate attenuation coefficient, and improper calibration of echo sounder systems and temperature and salinity sensors.

Considerations

Remediation

Determining whether trawl catch data are representative of species composition and length- and age-frequency distributions is complex. Comparison of data from different gear types used from the same vessel as close in time and space as possible could be useful in evaluating potential errors and designing corrections to be applied.

Improvements

Improvements in bottom tracking algorithms will greatly increase the efficiency of post-processing acoustic data and improve accuracy of the estimates. A bottom tracking algorithm failure in real-time might be corrected with a post-processing algorithm (such as that available in Echoview) or by comparison with or substitution by bottom detect data from a second echo sounder or frequency.

Introduction of new opening-closing nets with multiple cod ends attached to the end of a standard trawl will allow more discrete sampling. Trawls currently in use sample mid-water layers and schools of fish continuously throughout a deployment. Thus, samples of deeper layers contain fish caught in shallow layers, because the net is open on descent and ascent. Use of opening-closing gear will result in better characterization of targeted schools and layers, and will result more accurate length-frequency distributions.

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. Both broadband and multiple frequency systems are undergoing intensive development and testing, and may be introduced soon, at least on an experimental basis. Although some success has been achieved, especially for zooplankton (e.g., Martin *et al.* 1996), problems such as differences in the insonified volume between frequencies, short ranges associated with high frequencies, and change in noise levels with frequency must be overcome (see Reid (2000) for a brief review and bibliography). Such methods seem promising, and although multi-frequency studies of fish are still in their infancy, they are likely to be part of routine surveys in the future. Protocols for their use will be developed along with the systems themselves.

Underwater video and low ambient light level still-camera systems provide visual identification of species and have the potential to document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification

and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towed body orientation sensors (tilt, roll, and pitch) are also needed to quantify the data for behavioral measurements. Underwater video methods and techniques are currently under development. If these methods and techniques become routine part of a survey, protocols should be developed for video maintenance, data collection and archiving, and data analysis.

Performance Degradation

Definition & Importance

Performance degradation is the reduction in echo sounder performance due to mechanical, biological, or electrical processes.

Degradation in echo sounder performance can be caused by acoustical, vessel, and electrical noise, bio-fouling of the transducer face, excessive transducer motion, and bubble attenuation. Performance degradation differs from system performance in that the causes of performance degradation are external to the echo sounder, where as ‘system performance’ concerns the echo sounder electronics.

Routine monitoring of data by scientific personnel during data collection is necessary to ensure a high standard of data quality.

Techniques

Noise

Acoustical

A common type of acoustic noise is a discreet spike caused by another echo sounder or sonar operating within the frequency bandwidth or a harmonic of the scientific echo sounder. The solution is to identify the source of the interference and shut it down. A list of all acoustic systems with associated operating frequencies can aid in identifying the interfering system. Interference can be eliminated if acoustical instrumentation essential for safe ship operation is synchronized with the survey echo sounder. Removal of acoustic noise during post-processing is sometimes possible, but difficult, so eliminating it during the survey is always preferable.

Regional Protocols

Electrical

Electrical noise can be of many types. Electrical interference caused by improper grounding or other electrical systems can cause low-level voltage interference, spikes, or cyclical interference. A low level voltage introduced to the echo sounder can be amplified with range by the TVG function, and may pose a problem only in the deeper parts of the survey area. Problems can be reduced or eliminated by ensuring proper grounding of the scientific echo sounder, by using an uninterruptible power supply (UPS) for the scientific echo sounder, and by eliminating electrical interference during data collection. Electrical interference not eliminated during data collection should be removed during post-processing, either manually or with signal processing techniques. If signal processing techniques are used, care should be taken to ensure that target data is not modified, or correction factors may be required.

Regional Protocols

Bubble Attenuation

Bubbles can have a strong effect on propagation and transmission of sound. Due to the high acoustic impedance between air and water, bubbles are efficient scatterers of sound. Bubbles can increase attenuation (loss of signal strength) and potentially increase the probability of misclassification of gas-bearing organisms. Bubbles near the sea surface are generally associated with increased sea state and/or the position of the transducer relative to the vessel's hull. The transducer location on the hull must be chosen to minimize potential problems caused by bubbles. To prevent degradation of survey data, it is necessary to slow vessel speed or suspend acoustic survey operations when sea state causes unacceptable bubble attenuation. Currently, this decision is based on the judgment of the scientific field party chief, but explicit criteria need to be developed. In some cases, bubble backscattering can be removed from S_v data during post-processing, but this will not correct signal loss from targets of interest.

Regional Protocols

Transducer Motion

Excessive transducer motion is associated with increased sea state. Transducer motion affects bottom tracking, target strength and volume backscattering measurements. 'Dropouts' (i.e., reduction or elimination of S_v values over one or more pings) observed on the echogram are a clear indication of excessive transducer motion. If the vessel is outfitted with a motion sensor, these data should be recorded. Motion sensor data may be used for objective decisions on acoustic data quality or for making corrections to the acoustic data. Such corrections may be as high as 30% (MacLennan and Simmonds 1992). When sea state or vessel motion is excessive, as judged by the field party chief, survey speed must be slowed or operations must be suspended.

Regional Protocols

Bio-fouling

Bio-fouling can occur on hull-mounted transducers or protective coverings that stay in the water for long periods of time. Accumulation of material on the transducer will reduce the transmitted and received sensitivity, and this reduction may not be recognized by system performance procedures, although it should be detected by calibration. Hull-mounted transducers and protective coverings should be checked and cleaned regularly, and at a minimum before each field season.

Regional Protocols

Error

Bio-fouling will cause a systematic degradation in echo sounder performance as the bio-fouling increases. Transducer motion effects increase with increasing sea states, but the overall effect on abundance estimates requires investigation. Near-surface bubbles can be removed from the data during post-processing, however the resulting effects of bubble attenuation on S_v and acoustical estimates need to be studied. Most types of electrical and acoustical noise can be eliminated during data collection or post-processing. Noise that cannot be removed will increase S_v measurements and lead to overestimates of fish biomass.

Considerations

Remediation

If noise issues are found to be a problem, then analyses are required to determine the effects on S_v measurements. In most cases, noise can be removed from the data set by eliminating the problematic pings, but if the noise persists for long periods, removal is more difficult.

If motion sensor data are available, corrections can be made to the acoustic measurements (Dunford 2002).

Improvements

Better understanding of the effects of transducer motion and bubble attenuation will improve our ability to make adjustments to the S_v data or make objective decisions on when conditions preclude collecting useful data. The timing of pulses emitted by the echo sounder can be adjusted (adaptive pulse timing) so that the necessary correction is minimized. (Dunford 2002).

Systematic analyses are recommended to determine the effects of performance degradation on data quality. Results of these analyses will improve (or at least make possible) objective decisions during data collection.

Data Management

Volume backscattering data, post-processed data, biological, and associated meta-data should be routinely archived during the survey. These data are downloaded to shore-based computers and permanently archived for each survey. In addition to data, post-processing and other software should be archived.

Regional Protocols

Target Strength (σ_i)

Target strength and backscattering cross sectional area are the ability of a target to scatter sound back to the receiver. Target strength (TS) is defined as the base 10 logarithm of an intensity ratio:

$$TS \equiv 10 \log_{10} \left(\frac{I_r}{I_i} \right) \text{ dB re } 1 \mu\text{Pa} \quad (3)$$

where I_r is the received intensity, and I_i is the incident intensity at a distance of 1 m. The linear form of target strength is the backscattering cross sectional area (σ_{bs}):

$$\sigma_{bs} \equiv \left(\frac{I_{bs}}{I_i} \right) [m^2] \quad (4)$$

$$\sigma_{bs} = 10^{(TS/10)} \quad (5)$$

The term ‘target strength’ is often used as a generic reference to the backscattering characteristics of the target. One must be very careful to recognize that TS is a logarithmic value and not to confuse TS with the linear σ_{bs} when performing calculations.

When converting volume backscattering measurements (S_v) to numeric densities ($\# m^{-3}$), the calibrated echo energy (CE_i in equation 2) is scaled by the backscattering cross sectional area (σ_i in equation 2). Thus, an accurate σ_{bs} is critical for accurate density and abundance estimates.

Two general methods are available for obtaining an estimate of σ_{bs} . When organisms are acoustically resolvable, the *in situ* TS values from individuals can be used to scale S_v . When organisms are not acoustically resolvable, the σ_{bs} must be estimated by other means. A common method to estimate σ_{bs} is to use trawl catch length-frequency distributions and convert organism length (or some other metric of size) to target strength. This method requires a conversion from organism size to target strength. An empirically derived regression of the form $TS = \alpha \log_{10}(L) + \beta$, where L is fish length, is commonly used where α is traditionally set equal to 20 (Foote, 1987). Deriving this regression for surveyed species is not trivial. The regression requires a combination of *in situ* (if available) and *ex situ* measurements, and if possible, theoretical predictions of individual backscatter. Additionally, this equation is frequency dependent and should incorporate organism behavior and vertical distribution of target species encountered during the survey.

The treatment of target strength for abundance estimates depends on the objectives and use of acoustical estimates in fisheries assessments. Acoustic-based estimates as relative indices require a constant target strength over time and among surveys. If acoustical abundance estimates are to be used as absolute values, accurate TS measurements must be obtained for every survey. Due to the complexity involved with deriving an accurate TS-length equation, acoustical estimates are often treated as relative abundances.

Models

Definition & Importance

Acoustical models used in fisheries acoustics are mathematical constructs derived to describe a relationship between acoustical energy and biological metrics.

Acoustical backscattering models include numerical and analytical derivations based on acoustical theory, and empirically derived relationships between acoustical energy and

biological metrics. These models are used to predict acoustical backscattering by the species being surveyed.

Techniques

Theoretical

Numerical and analytical models have been developed to predict acoustical backscatter as a function of organism size, shape, anatomical characteristics, orientation, and acoustic frequency for zooplankton and fish. These models have advantages and limitations when applied to different organism types. The models range in complexity from approximating organism anatomy and morphometry as simple shapes to utilizing three-dimensional digital images of organism internal structures. Advantages to theoretical models are that once verified, predictions over a wide range of conditions (*i.e.*, acoustic frequency, behavior, biological state) can be tabulated. Difficulties with applying models to survey data are obtaining accurate representations of *in situ* organism anatomy, morphometry and orientation, and verifying the predictions. Currently for fish, model results have only been used to develop a TS-length equation for Atlantic herring in the North Sea.

Regional Protocols

Empirical

Empirical methods relating target strength to organism size include *in situ* measurements and *ex situ* laboratory experiments. *In situ* methods are advantageous because the target strengths incorporate behaviors and vertical distributions observed during the survey. Limitations are obtaining representative length-frequency distributions of the insonified organisms, the organisms must be acoustically resolved, and predictions are limited to the range of organism size and behavior observed. *Ex situ* measurements are controlled or semi-controlled experiments where individuals or groups of known sizes are insonified. Disadvantages to *ex situ* measurements are difficulties in replicating *in situ* conditions and uncertainty in applying *ex situ* measurements to survey conditions.

Regional Protocols

Validation

Validating target strength measurements relative to organism size, behavior, and biological conditions encountered during surveys is difficult. Empirical methods are limited to the range of measurements. Numerical and analytical models can predict acoustical scattering over a wide range of conditions, but verifying model predictions is difficult.

Regional Protocols

Error

If volume backscattering measurements are to be converted from relative indices to absolute values, accuracy and precision of target strength measurements are critical. Assuming correctly calibrated echo sounders, target strength is the sole scalar for calculating absolute density. A 3 dB error in target strength leads to a factor of two in uncertainty for density and abundance estimates. Due to the complex nature of organism anatomy and behavior, acoustical backscattering by biological targets is complicated. Uncertainty in target strength measurements and predictions is a combination of systematic and random errors, which can be difficult to separate.

Considerations

Remediation

If a TS-length regression is found to be incorrect or numerical and analytical model predictions are found to be erroneous, and these results were incorporated in survey estimates, then analyses must be performed to determine the effect of these errors in population estimates.

Improvements

Significant effort improving and verifying target strength predictions by numerical and analytical models is required. Improved understanding and characterization of target strength relative to organism size and behavior is required. Even if TS measurements are not directly used in survey estimates, target strengths can be useful for evaluating changes in S_v .

Data Collection

Definition & Importance

Target strength data collection is the operational procedures used to acoustically resolve individuals.

Target strength is an important scalar for converting S_v measurements to absolute values. Organisms must be acoustically resolvable for valid target strength measurements. Acoustic resolution is defined as the ability to separate echoes among individuals and is based on the pulse duration (τ) and sound speed (c):

$$R_2 - R_1 > \frac{c\tau}{2} \quad (6)$$

where the R 's are the ranges for two targets (subscript 1 and 2) (MacLennan and Simmonds, 1992).

Techniques

Echo sounder Parameters

A generic method to separate echoes by individuals involves selecting peak amplitudes above a threshold, measuring the echo width (either time- or range-based), and comparing the echo width to the pulse duration. Different echo sounder manufacturers apply this single target detection method differently. It is important to understand the specific method the echo sounder uses and the parameter settings employed.

Regional Protocols

Software

As with echo sounder manufacturers, different post-processing software packages apply single target detection algorithms differently. It is important to understand the specific method and parameters used by post-processing software, and to document the algorithms, parameters, and software versions.

Regional Protocols

In situ data

Collecting *in situ* target strength data should be a routine operation during surveys and is as important as collecting biological data regardless of the ultimate use of target strength data in survey estimates. Target strength data can be collected while transecting and/or at selected sites. Numbers, locations, and timing of target strength operations are dependent on the objectives of the survey.

Regional Protocols

GPS

Integrating Global Positioning System (GPS) data with TS measurements are imperative for using target strength data in survey estimates. Choice of positioning data is dependent on the availability of the GPS systems on-board, performance of the GPS over the survey area, compatibility of the GPS system with the echo sounder, and the desired accuracy and precision of the GPS data.

Regional Protocols

Oceanographic Data

Sea-surface and vertical profiles of temperature and salinity are required for ensuring that the sound speed is calculated correctly. Sea-surface and vertical profiles of temperature and salinity should be collected in conjunction with target strength data. Temperature and salinity data can also be useful for measuring the physical environment for ecological studies

Oceanographic sensor manufacturers provide calibration, operational, and diagnostic instructions. These instructions should be followed.

Regional Protocols

Error

Uncertainty in single target detection parameters and data collection procedures affects the accuracy and precision of target strength data. Systematic or random errors in selecting and relating target strength data to S_v measurements will influence population estimates by introducing errors in the scaling of S_v data to estimates of density and abundance.

Considerations

Remediation

Application of target strength data to S_v measurements is completed after the survey has been completed and is a component of deriving abundance and biomass estimates. Collecting *in situ* target strength measurements requires calibrated echo sounders, and remediation protocols equivalent to those used for S_v measurements should be maintained.

Improvements

Improvements in single target detection, such as multiple frequency techniques (Demer et al., 1999), will increase the accuracy and precision of target strength measurements and ultimately survey estimates.

Detection Probability

Definition & Importance

Target strength detection probability is the likelihood of detecting echoes from individual organisms.

Single target detection probability is dependent on the TS threshold and other parameter settings ('Target Strength Data Collection' section) and the behavior of the organisms. Organism orientation strongly affects target strength, as does the vertical distribution. Organisms on the edge of the beam will have lower detection probabilities due to the acoustic beam pattern. Organisms near the surface and seabed will also have lower detection probabilities.

Techniques

Beam Pattern

Transducers used in fisheries acoustics are used to transmit and receive sound. These transducers are directional where the sensitivity decreases as a function of angular distance from the acoustic axis. Relevant transducer parameters for target strength measurements are the beam width and the directivity response function. Beam width is measured as the total angular distance at the half-power points (i.e., 3 dB 'down-points'). The directivity response is measured as the two-way (transmit and receive) sensitivity as a function of angular location in the acoustic beam. The two-way integrated beam pattern (ψ) used in S_v measurements is the surface integration of the directivity response function. Due to the directivity of a transducer, the echo strength of an organism will be greater on-axis than off-axis. To measure the target strength of the organism, the echo strength must be compensated for location in the acoustic beam. Split-beam transducers

measure the angular location of a target and compensate echo strength by the directivity response.

Regional Protocols

Thresholding

The first criterion for single target detection is the TS threshold, where peak echo amplitudes greater than the threshold are further evaluated as single targets. Thresholding is useful for eliminating target strength measurements from non-target organisms. However, applying a TS threshold can eliminate target strengths from desired species. Thus selecting an optimal threshold should incorporate knowledge of targets strengths from the species of interest and non-target species and the behavior of the targets.

Regional Protocols

Acoustic Dead Zones: Near Bottom and Near Surface

Similar to S_v measurements, organisms located above the transducer and within a few meters of the transducer are not measured. In addition, organisms must be in the far field of the transducer for valid target strength measurements. Resolving organisms near the seabed is dependent on the range resolution of the echo sounder (pulse length dependent) and the topography of the bottom. Single target detection probabilities near the seabed are reduced over rough bottom topography.

Regional Protocols

Animal Behavior

Organism behavior includes activities such as vertical migration, swimming, and feeding and the orientation of the organism relative to the transducer. In general, for acoustic frequencies in the geometric scattering region, target strength is greatest when the major axis of the organism is aligned perpendicular to the transducer. In the case of fish with swimbladders, maximum TS occurs when the major axis of the swimbladder is aligned perpendicular to the transducer. Target strength decreases significantly as the major axis of the organism aligns parallel to the acoustic axis. The detection probability may be dependent on organism orientation if the target strength at low aspect angles is below the TS threshold.

Regional Protocols

Vessel Noise

Vessels radiate underwater noise. Depending on the characteristics of the noise spectrum, a number of fish species are able to detect the vessel noise. An issue is

whether the fish react to the vessel noise, thereby altering their behavior and detection probability. Vessel avoidance is defined as a zero detection probability resulting from a change in behavior due to the vessel noise. Less severe changes in behavior may affect the TS measurements and the detection probability. Urick (1983) details radiated vessel noise. The ICES Cooperative Report (Mitson 1995) provides an overview of the issues relating to acoustical surveys of fish.

Avoidance of fisheries vessels is a complex issue. A number of fish species have the ability to detect vessel noise, but whether avoidance or other behavioral changes occur is difficult to document. Physical environmental conditions such as the presence of a thermocline or halocline, animal vertical distribution, and biological factors such as spawning or feeding combine to influence organism behavior. Fundamental methods for investigating vessel avoidance are to obtain a vessel noise spectrum and to monitor the vessel noise during a survey.

Regional Protocols

Density Requirements

Single target detections are dependent on the range resolution and the density of organisms. As the organism density increases, the distance between organisms decreases to where single target discrimination is not feasible. At increased ranges, the signal-to-noise ratio (SNR) increases, which decreases the ability to detect single targets. Methods to objectively determine when single target detections are valid (Sawada *et al.* 1993; Gauthier and Rose, 2001) have been developed and should be used when incorporating *in situ* TS measurements.

Regional Protocols

Single Frequency

Methods using single frequency data have been derived to estimate the density at which valid TS measurements can be obtained (Sawada *et al.* 1993; Gauthier and Rose, 2001). These methods require *a priori* knowledge of the target strength distribution.

Regional Protocols

Multiple Frequency

A method to increase the accuracy and precision of target strength measurements using multiple frequencies was derived by Demer *et al.* (1999). Using the geometry of the transducer locations (accurate measurements of the transducer locations are required) and acoustical beam directivities (accurate measurements of the beam directivities are required), improper single-target detections by individual frequency algorithms are greatly reduced, thus increasing confidence in *in situ* TS measurements.

Regional Protocols

Error

When using a calibrated echo sounder, target strength is the sole scaling factor for converting relative indices to absolute estimates. Thus obtaining a representative target strength for the target species is imperative. Systematic and random changes in detection probabilities during the survey will have linear and non-linear effects on target strength measurements. Uncertainties in target strength detection probabilities will affect *in situ* target strength measurements and ultimately bias scaling S_v measurements to absolute density estimates. Uncertainty in detection probabilities of target and non-target species affects interpretation of target strength measurements and the efficacy of post-processing techniques. Errors in beam pattern measurements and echo sounder gains will contribute to systematic biases of TS measurements. Improper thresholds may unnecessarily eliminate or include measurements of non-target species, which will systematically bias measured target strength distributions. Vessel noise and behavioral attributes may introduce random errors in target strength measurements. A systematic change in fish orientation, for example, from a horizontal to a more vertical position during vertical migration, will cause a decrease in TS. If factors such as orientation are not taken into account, target strength to length regressions will be in error.

Considerations

Remediation

The survey design (timing and location) should consider potential systematic changes in detection probability. If systematic changes in detection probability are discovered, either a change in the survey design is required or analyses should be conducted to determine a correction factor. If significant changes are made to the survey vessel that are expected to affect vessel-generated noise (e.g. major modifications to propeller, generators, or main engine), noise-range measurements should be conducted.

The TS threshold should be modified if organisms on the lower end of the target strength distribution are not detected.

If beam pattern and TS gain calibrations indicate problems with the echo sounder and transducer, these problems need to be evaluated (refer to the Calibration section) before the survey can commence.

Improvements

Incorporating theoretical acoustical backscattering models to determine target strength distributions may improve operational protocols for collecting target strength measurements. Simulations of the effects of detection probability on absolute density and abundance estimates should be conducted to determine the extent of biases in population estimates.

The first of four low-noise NOAA survey vessels is currently under construction and will begin survey work for the AFSC in 2005. The NEFSC, NWFSC, and SWFSC will each receive one of the other vessels. All four vessels will meet ICES noise standards, which will greatly reduce the potential for vessel noise affecting fish behavior.

Classification

Definition & Importance

Classification is the discrimination, categorization, and identification of organism type or species.

Target strength measurements are used to scale S_v measurements to absolute density and abundance. Target strength measurements are classified to species and age- or length-classes based on acoustical and ancillary information. Scaling species and age- or length-based S_v measurements requires that target strength measurements be obtained from the species of interest, which requires classification of target strength measurements.

Techniques

Single Frequency

In mixed-species aggregation or even single-species aggregation conditions, classifying target strength measurements using single frequencies is difficult. The standard frequency for estimating density and abundance of marine fish species is 38 kHz. Echo sounders operating at 38 kHz are able to detect juvenile and adult fish with a swimbladder, juvenile and adult fish without a swimbladder, and macrozooplankton such as euphausiids and krill. The ability to measure backscatter by a wide variety of organisms is advantageous in that 38-kHz echo sounders can be used for a diversity of species. The disadvantage is separating backscatter from target species is difficult. Due to this difficulty, multiple frequency data are utilized in conjunction with biological sampling to classify acoustical data to species.

Regional Protocols

Multiple Frequency

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. The efficacy of multiple narrow-band frequencies to classify target strength data is based on the frequency dependent scattering by different types of organisms. In general, more frequencies do not necessarily equate to better classification, but a judicious choice of frequencies can improve classification techniques.

Regional Protocols

Biological Sampling

Trawls

Pelagic trawls are the primary tools for validating the species composition of acoustic backscatter and for obtaining length frequency distribution, age, and other biological information. Trawls provide the best available method of obtaining relatively unbiased estimates of species and size composition (Simmonds *et al.* 1992). Appropriate trawl gear should be chosen with full consideration of its size in relation to the towing power of the vessel. The number, locations, and timing of trawl sets are dependent on the objectives

of the survey, but the main idea is to obtain catches that are representative of the species composition and the length-frequency distribution of organisms detected acoustically. This is difficult to accomplish because nearly all biological sampling methods are species and size selective.

Different parts of a school or layer may have different length-frequency distributions or even different species compositions, and a single school may not be representative of the cluster of schools in an area. For this reason, hauls should include more than one small school and more than one part of a large school or layer if this can be done without taking a sample that cannot be handled by the vessel.

Trawls in acoustical surveys are targeted on schools or layers detected by the echo sounder. Such aimed trawling requires effective net mensuration instrumentation. Net mensuration instrumentation choices include door and wing sensors, third-wire sensors, depth sensors, and head- and footrope sensors. Although net catches for hauls made during acoustical surveys are not used for estimating fish biomass, it is still important that trawl procedures are consistent between and within surveys. Net mensuration information is essential for maintaining consistency and evaluating performance in trawl procedures.

In many cases trawl catches are too large to sample in their entirety, and must be sub-sampled. Even when an entire trawl catch is processed for species composition by weight and number, additional information such as age, fish length and sex cannot, in most cases, be taken from all captured specimens. Thus, random sub-samples of the catch should be taken to obtain the biological information. Determination of the sub-sample size should be guided by statistical principles.

Protocols for setting and retrieving the net should be based on the type of net and vessel. Vessel personnel play a key role in maintaining repeatability in net deployment, and should be briefed on the importance of adhering to protocols. They should have a copy of the protocols and should be consulted in the development of the trawl field manual. Routine inspections of the gear should be made to confirm that it conforms to design specifications. This is especially important after nets have been damaged and repaired in the field.

A schedule for calibration and maintenance of net mensuration equipment should follow the manufacturer's recommendations. If possible, spare parts or complete backup systems should be available for all critical net mensuration instruments.

Regional Protocols

Underwater video.

Underwater video and still-camera systems provide visual identification of species and potentially can document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and

towbody orientation sensors (tilt, roll, and pitch) are also required to quantify the data for behavioral measurements.

Regional Protocols

Bottom Tracking

Echo sounders and post-processing software use algorithms to detect the seabed. Depending on bottom type and topography, performance of these algorithms varies. On hard, flat substrate, the algorithms perform well. On soft substrate, or rugged topography, the ability to accurately detect the bottom degrades. The echo strength from the seabed is typically orders of magnitude greater than the echo strength from biological organisms, thus eliminating seabed echoes from the water column data is imperative. Improper bottom detections are found and corrected manually through inspection of the echograms. Bottom detection parameters used during data collection and in post-processing should be documented.

Regional Protocols

Error

When using a calibrated echo sounder, target strength is the sole scaling factor for converting relative indices to absolute estimates. Thus obtaining a representative target strength for the species of interest is imperative. Uncertainty in target strength classification will increase biases when scaling S_v measurements to absolute density and abundance estimates. Uncertainty in classifying and separating acoustic backscatter by target species from non-target species is a potential source of error in acoustical estimates of density and abundance. Possible errors include misclassification (either incorporating target strengths by non-target species or eliminating target strengths by target species), relating target strength measurements to trawl catch data that are not representative of species composition or length- and age-frequency distributions, incorporating seabed echoes in water column data, use of an inappropriate attenuation coefficient, and improper calibration of echo sounder systems and temperature and salinity sensors.

Considerations

Remediation

Determining whether trawl catch data are representative of species composition and length- and age-frequency distributions is complex. Comparison of data from different gear types used from the same vessel as close in time and space as possible could be useful in evaluating potential errors and designing corrections to be applied.

Improvements

Improvements in bottom tracking algorithms will greatly increase the efficiency of post-processing acoustic data and improve accuracy of the target strength distributions for demersal species. A bottom tracking algorithm failure in real-time might be corrected

with a post-processing algorithm (such as that available in Echoview) or by comparison with or substitution by bottom detect data from a second echo sounder or frequency.

Introduction of new opening-closing nets with multiple cod ends attached to the end of a standard trawl will allow more discrete sampling. Trawls currently in use sample mid-water layers and schools of fish continuously throughout a deployment. Thus, samples of deeper layers contain fish caught in shallow layers, because the net is open on descent and ascent. Use of opening-closing gear will result in better characterization of targeted schools and layers, and will result more accurate length-frequency distributions and relationships of target strength to length.

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. Both broadband and multiple frequency systems are undergoing intensive development and testing, and may be introduced soon, at least on an experimental basis. Although some success has been achieved, especially for zooplankton (e.g., Martin *et al.* 1996), problems such as differences in the insonified volume between frequencies, short ranges associated with high frequencies, and change in noise levels with frequency must be overcome (see Reid (2000) for a brief review and bibliography). Such methods seem promising, and although multi-frequency studies of fish are still in their infancy, they are likely to be part of routine surveys in the future. Protocols for their use will be developed along with the systems themselves.

Underwater video and low ambient light level still-camera systems provide visual identification of species and have the potential to document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towed body orientation sensors (tilt, roll, and pitch) are also needed to quantify the data for behavioral measurements. Underwater video methods and techniques are currently under development. If these methods and techniques become routine part of a survey, protocols should be developed for video maintenance, data collection and archiving, and data analysis.

Developing objective classification criteria will require incorporating theoretical acoustical backscattering models and *ex situ* laboratory measurements in classification techniques. The integration of *in situ* and *ex situ* measurements and analytical predictions as routine methods will significantly improve our ability to classify and identify acoustical backscattering and improve the accuracy and precision of population estimates.

Performance Degradation

Definition & Importance

Performance degradation is the reduction in echo sounder performance due to mechanical, biological, or electrical processes and mechanisms.

Degradation in echo sounder performance can be caused by acoustical and electrical noise, bio-fouling of the transducer face or cables, excessive transducer motion, and bubble attenuation. Performance degradation differs from system performance in that the

causes of performance degradation are external to the echo sounder, where as system performance accounts for the echo sounder electronics. Additionally, performance degradation is often not observed until the resulting effects are greater than the TS threshold.

Routine monitoring of data by scientific personnel during data collection is necessary to ensure a high standard of data quality.

Techniques

Noise

Acoustical

A common type of acoustic noise is a discreet spike caused by another echo sounder or sonar operating within the frequency bandwidth or a harmonic of the scientific echo sounder. The solution is to identify the source of the interference and shut it down. A list of all acoustic systems with associated operating frequencies can aid in identifying the interfering system. Interference can be eliminated if acoustical instrumentation essential for safe ship operation is synchronized with the survey echo sounder. Removal of acoustic noise during post-processing is sometimes possible, but difficult, so eliminating it during the survey is always preferable.

Regional Protocols

Electrical

Electrical noise can be of many types. Electrical interference caused by improper grounding or other electrical systems can cause low-level voltage interference, spikes, or cyclical interference. A low level voltage introduced to the echo sounder can be amplified with range by the TVG function, and may pose a problem only in the deeper parts of the survey area. Problems can be reduced or eliminated by ensuring proper grounding of the scientific echo sounder, by using an uninterruptible power supply (UPS) for the scientific echo sounder, and by eliminating electrical interference during data collection. Electrical interference not eliminated during data collection should be removed during post-processing, either manually or with signal processing techniques. If signal processing techniques are used, care should be taken to ensure that target strength distributions are not modified, or correction factors may be required.

Regional Protocols

Bubble Attenuation

Bubbles can have a strong effect on propagation and transmission of sound. Due to the high acoustic impedance between air and water, bubbles are efficient scatterers of sound. Bubbles can increase attenuation (loss of signal strength) and potentially increase the probability of misclassification of gas-bearing organisms. Bubbles near the sea surface are generally associated with increased sea state and/or the position of the transducer relative to the vessel's hull. The transducer location on the hull must be chosen to minimize potential problems caused by bubbles. To prevent degradation of

survey data, it is necessary to slow vessel speed or suspend acoustic survey operations when sea state causes unacceptable bubble attenuation. Currently, this decision is based on the judgment of the scientific field party chief, but explicit criteria need to be developed. In some cases, bubble backscattering can be removed from target strength data during post-processing, but this will not correct signal loss from targets of interest.

Regional Protocols

Transducer Motion

Excessive transducer motion is associated with increased sea state. Transducer motion affects bottom tracking, target strength and volume backscattering measurements. ‘Dropouts’ (i.e., reduction or elimination of TS values over one or more pings) observed on the echogram are a clear indication of excessive transducer motion. If the vessel is outfitted with a motion sensor, these data should be recorded. Motion sensor data may be used for objective decisions on acoustic data quality or for making corrections to the acoustic data. When sea state or vessel motion is excessive, as judged by the field party chief, survey speed must be slowed or operations must be suspended.

Regional Protocols

Bio-fouling

Bio-fouling can occur on hull-mounted transducers or protective coverings that stay in the water for long periods of time. Accumulation of material on the transducer will reduce the transmitted and received sensitivity, and this reduction may not be recognized by system performance procedures, although it should be detected by calibration. Hull-mounted transducers and protective coverings should be checked and cleaned regularly, and at a minimum before each field season.

Regional Protocols

Error

Bio-fouling will cause a systematic degradation in echo sounder performance as the bio-fouling increases. Transducer motion effects increase with increasing sea states, but the overall effect on abundance estimates requires investigation. Near-surface bubbles can be removed from the data during post-processing, however the resulting effects of bubble attenuation on target strength need to be studied. Most types of electrical and acoustical noise can be eliminated during data collection or post-processing. Noise that cannot be removed will bias target strength measurements and lead to errors in fish biomass estimates.

Considerations

Remediation

If noise issues are found to be a problem, then analyses are required to determine the effects on target strength measurements. In most cases, noise can be removed from the data set by eliminating the problematic pings, but if the noise persists for long periods, removal is more difficult.

If motion sensor data are available, corrections can be made to the acoustic measurements (Dunford 2002).

Improvements

A better understanding of the effects of transducer motion and bubble attenuation will improve our ability to make adjustments to the target strength data or make objective decisions on when conditions preclude collecting useful data. The timing of pulses emitted by the echo sounder can be adjusted (adaptive pulse timing) so that the necessary correction is minimized. (Dunford 2002).

Systematic analyses are recommended to determine the effects of performance degradation on data quality. Results of these analyses will improve (or at least make possible) objective decisions during data collection.

Data Management

Target strength data, post-processed data, biological, and associated meta-data should be routinely archived during the survey. These data are downloaded to shore-based computers and permanently archived for each survey or portion of a survey. In addition to data, post-processing and other software should be archived.

Regional Protocols

Sampling

Survey Design (A_i)

Definition & Importance

The design of an acoustic survey, as the consideration of the collection methods and analytic processes employed to meet the informational objectives and goals of a particular survey, manifests in the execution of the survey cruise track.

Since fishery acoustic survey results are based on sampling (as opposed to a census), the principal importance of the choice of the area sampled relates directly to the accuracy and precision of the resulting population estimate and, importantly, the ability to understand, manage, control and report on all known sources of error that impact on the quality of the resulting estimate.

In most marine fishery acoustic surveys, and in particular those addressed in this protocol, the echo sounder instrumentation is deployed off ocean-going vessels. In these mobile surveys, acoustic measurements – principally volume or area backscattering – are made along pre-determined transects that encompass an area (A_i) inhabited by the organisms of interest. The placement of transects, their spacing and orientation, and other aspects of sampling time or sampling frequency are not only determined by the

population estimation goals of the survey but also by the practical constraints of vessel logistics and other resources available.

Techniques

Transect-based surveys are developed around the knowledge that the measurements made along the survey tracks are samples of the wider distribution of the target species. Since only a portion of the overall area of concern is actually sampled, any survey design consists of choices that need to address specific objectives, which can vary from an overall estimate of abundance for an entire population to simply the identification of locations of fish concentrations. In each instance, the informational demands of the survey need to be fully reflected in the survey design as they pertain to the objectives of the survey, to any *a priori* knowledge of stock distribution, and importantly, to the analytical method to be used for analysis (ICES 1993). Assumptions also need to be recognized and addressed in the design, especially where changes in fish behavior or distribution may impact those assumptions. The general guidelines for planning and conducting an acoustic survey as listed by MacLennan and Simmons (1992) include:

- 1) Definition of the geographic area to be covered;
- 2) Estimation of the resources required to adequately sample the area, including all methods;
- 3) Calculation of the time available to conduct all operations;
- 4) Decision on the sampling strategy and type of cruise track; and
- 5) Plot of the cruise tracks on a chart [or navigation plotting software] to check survey design feasibility.

Within the area under consideration, the choice of spacing and track layout (e.g., systematic parallel, random parallel, systematic zig-zag) should reflect an understanding of the serially correlated nature of the acoustic sampling technique and a consideration of the expected patchiness of the population of interest. With an obligation for intra-transect interpolation of the acoustic observations, objectivity is paramount in this decision. Moreover, the confidence in any particular estimate is reflected ultimately in the associated error. Jolly and Hampton (1990) demonstrate the gain in precision based on a stratified random design where practicable. However, where the demands on an acoustical survey by random sampling theory may not be practicable, the application of regularly spaced transects may be used to efficiently ensure adequate coverage. In these situations, the spatial correlation must be modeled and geostatistics may be the best tool for estimates of precision of the total population estimate (Petitgas 1993).

- 1) Describe and defend choice of survey track layout;
- 2) Explore acoustic data for spatial, temporal, and multivariate structure of the population of interest for development of appropriate error structure and subsequent improvements in survey design.

Vessel Speed

Vessel speed is a survey aspect that requires consideration. Choosing an operational speed is a balance between coverage, data quality, and vessel limitations. Ten knots is a common vessel speed while conducting fisheries acoustics transects. However, as sea state increases, vessel speed often will need to decrease to maintain data quality owing to increased noise and the influx of bubbles across the face of the transducer due to

cavitation – not to mention considerations due to vessel pitch and roll effects on transducer motion (Stanton 1982). At some sea state, data quality cannot be maintained and survey operations must be suspended. Criteria based on sea state and data quality standards need to be developed (refer to the Volume Backscattering Measurements and Target Strength Performance Degradation sections).

Regional Protocols

GPS

Integrating Global Positioning System (GPS) data with acoustical measurements are critical for population estimates. GPS data are required for measurements of a species spatial distribution and determining vessel location relative to physical oceanographic conditions and topographic features. Choice of positioning data is dependent on the availability of the GPS systems on-board, performance of the GPS over the survey area, compatibility of the GPS system with the echo sounder, and the desired accuracy and precision of the GPS data.

Regional Protocols

Error

Uncertainty and random and systematic errors in survey design include inadequate sampling of the organism's spatial distribution, incomplete coverage of the population, and incorrect timing of the survey relative to seasonal migrations or other behaviors.

Considerations

Remediation

If intolerable errors or bias in a survey design are either observed directly or inferred from population dynamics modeling, a new survey design must be implemented. However, changes in the design must be considerate of the possible impacts to a time series.

Improvements

Improvements in survey design include the use of vessels designed for conducting acoustic surveys (allowing faster operation at lower radiated noise), and the incorporation of platforms such as buoys and AUV's to augment vessel surveys.

Numerical Density to Biomass Density (D_i)

Definition & Importance

Numerical density to biomass density is the conversion of acoustical energy to organism size (e.g., length, equivalent volume) and biomass. This conversion is done during data analysis, and hence detailed data collection protocols do not apply. Specific data collection protocols for target strength, S_v , and fish lengths are detailed in their respective sections.

Species-specific biomass density and abundance estimates are the end result of fisheries acoustics surveys. Converting acoustical energy to biomass is a multi-step procedure. S_v [$\text{m}^2 \text{m}^{-3}$] measurements are scaled to numerical density [$\# \text{m}^{-3}$] by target strength. Target strengths are obtained from *in situ* measurements and empirical or numerical and analytical regressions of target strength to organism size. Volume densities are vertically integrated to give areal densities [$\text{m}^2 \text{m}^{-2}$] along the cruise track, and areal densities are scaled to the survey area. The marine convention is to scale areal density to square nautical miles [$1 \text{ nmi}^2 = (1852)^2 \text{ m}^2$]. Biomass is obtained from organism size to biomass regressions tabulated from net catch data. If age- or length-based estimates are desired, the same steps are done for each age or length class.

Acoustical energy to biomass conversions integrate results from data collection, post-processing, and analysis and as such, incorporate and accumulate errors from all steps. An error budget that includes all sources of error is necessary.

Techniques

Target Strength to Length Regression

The target strength-to-length regression is the conversion of acoustical energy to fish length. Application of the target strength-to-length regression is completed during data analysis. Data collection protocols are detailed in the target strength data collection sections.

Fish length is the standard measure of a fish's size. However, a few measures of fish length are used. Fish lengths are measured as the total length, fork length, or standard length and in units of centimeters or millimeters. Target strength to length regressions are derived for a specific measurement type of fish length and unit of measure. When reporting TS-length regressions, the measurement type and units must be documented. Conversions among length measurement types can be tabulated as regressions, such as fork length to total length, but be aware that these add an additional layer of error and bias.

Regional Protocols

Length-Weight Regression

A length-weight regression is an empirical relationship between a fish's length and weight (or biomass). Application of the length-to-weight regression is completed during data analysis. Data collection protocols are detailed in the volume backscattering biological data collection sections.

The length-weight relationship is a common measure of fish growth. It is also a necessary regression to convert fish abundance to fish biomass. The length-weight regression is often defined as: $W=aL^b$, where W is fish mass, L is fish length, and a and b are empirically derived coefficients. The coefficients a and b are derived for specific length measurement types (e.g., fork length) and measurement units.

Regional Protocols

Error

Uncertainty and random and systematic errors in conversions of acoustical energy to species-specific biomass accumulate errors throughout the data collection, post-processing, and analysis steps. An overall error budget should be done.

Considerations

Remediation

If there is an indication of length or weight differences within a survey area, length-weight regressions should be tabulated at multiple stations during a survey.

Improvements

Improvements in *in situ* and *ex situ* target strength measurements and the relationships between target strength and fish lengths will significantly improve conversion of relative indices to absolute indices.

Oceanographic Data

Definition & Importance

Oceanographic data include temperature, salinity, and depth measurements.

Temperature and salinity measurements are required for computing sound speed and are important for calibrations, S_v and TS measurements, species classification, and ecological studies. Temperature and salinity measurements are collected at the sea surface and throughout the water column (CTD profiles).

Techniques

CTD profiles

Conductivity-Temperature-Depth (CTD) sensors measure temperature, salinity (computed from conductivity), and depth. Lowering and raising the CTD at a station provides a vertical temperature and salinity profile. Collecting temperature and salinity data are dependent on the objectives of the survey.

Regional Protocols

Surface temperature and salinity

Sea surface temperature and salinity data are obtained with hull-mounted sensors. These sensors provide real-time data and can be used to detect surface fronts. Surface temperature and salinity sensor can be placed at multiple depths on the hull. Sea surface temperatures can also be obtained from satellites, although are limited to relatively cloud-free periods.

Regional Protocols

Scientific Computer System (SCS)

Definition & Importance

The Scientific Computer System (SCS) is a shipboard system that logs data from sensors.

The Scientific Computer System (SCS) continuously collects and electronically records navigational, oceanographic, and meteorological data from shipboard sensors. The SCS system continuously samples data streams from shipboard instrumentation at regular intervals throughout the cruise periods. Approximately 150 data variables are collected, including date and time (GMT), multiple latitude and longitude positions (PCODE, differential, LORAN), water and air temperatures, salinity, fluorometry, wind speed, pitch and roll, and bottom depths and vessel log values from the EK500.

An electronic 'event log' can be developed based on the SCS system. The event log is a data management tool for relating echo sounder data with scientific operations. When operational, the event log is routinely completed throughout each cruise to document chronological events of the acoustic sampling, deployments, and other operational details that are important for data processing and management. The event log can be used to register the start and stop of transects, gear deployments, sites and transect series and associated data such as date-time stamps, geographic location, EK500 vessel logs, and comments during survey operations.

Techniques

Event Log

Regional Protocols

SCS data

Regional Protocols

Error

Uncertainty in temperature and salinity affect sound speed calculations, which affect all acoustical measurements. Temperature and salinity sensors must be calibrated to ensure high quality oceanographic measurements.

Errors in logging and recording events will reduce the accuracy of survey estimates because acoustical data will be improperly related to transects or deployments. While the information is redundantly entered on a hard copy version of the event log, every effort must be insured to accurately enter information in the electronic event log.

Considerations

Remediation

If temperature and salinity measurements are found to be in error, corrections to the oceanographic data should be implemented and new sound speeds calculated. If a significant change in sound speed is found, acoustical data should be reanalyzed.

If errors in the event logging software or SCS data are observed during the survey, contact the electronics technician on board to rectify the problem.

Improvements

Acoustical data are continuous in two dimensions (vertical and along the ship track). CTD profiles provide vertical measurements at a single point along the cruise track and surface sensors provide one-dimensional measurements along the cruise track. Interpolation and extrapolation of these data are necessary to match the physical environment to the acoustical data. An improvement would be having the ability to collect two-dimensional temperature and salinity measurements.

Data Management

Data, post-processed data, and associated meta-data should be routinely archived during the survey. These data are downloaded to shore-based computers and permanently archived for each survey. In addition to data, post-processing and other software should be archived.

Regional Protocols

Modifications to Protocols

Changes to operational protocols will be at the discretion of the appropriate Science Director who may approve such changes directly or specify a peer review process to further evaluate the justification and impacts of the proposed changes.

We recommend that a national standing working group be established to coordinate development of national and regional protocols, to share information among the centers, and to improve the techniques of acoustical surveys.

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